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# Vulnerability of Persian Gulf Desalination Systems: An Emerging Security Issue

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A Research Paper



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# Vulnerability of Persian Gulf Desalination Systems: An Emerging Security Issue [redacted] 25X1

**A Research Paper**

This paper was prepared by [redacted] Office of Global Issues. Comments and queries are welcome and may be directed to the Chief, Resources Analysis Branch, OGI, [redacted] 25X1 25X1

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# Vulnerability of Persian Gulf Desalination Systems: An Emerging Security Issue

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**Overview**

*Information available as of 20 August 1983 was used in this report.*

Potable water is a strategic commodity in most Persian Gulf countries. Indeed, senior government officials in some of the countries perceive it as more important than oil to the national well-being. Seawater desalination is increasingly the primary source for this precious commodity. Although national dependence on desalinated water varies substantially among Persian Gulf countries, disruption of desalination facilities in most of the Arab countries could have more serious consequences than the loss of any other industry or commodity:

- Saudi Arabia—with the world's largest desalination plant construction and operations program—currently desalinates well over half of its potable water in the critical Eastern Province.
- Kuwait, the United Arab Emirates, and Qatar are, for all practical purposes, completely dependent on desalination for potable water supplies. Each obtains more than 80 percent of their municipal water supplies from desalination and are extremely vulnerable to disruptions.
- Bahrain, which recently became aware of the rapid depletion of its major aquifer (water-bearing stratum of permeable rocky sand or gravel), currently obtains about half its municipal water supplies from desalination and will become even more dependent on desalination by the end of the decade.
- Iran and Iraq, with small coastal populations and substantial available natural water sources, have little need for desalination. 25X1

The need for desalinated water is expanding primarily because of rapid industrialization and urbanization among the Arab countries of the Gulf. Natural freshwater resources are, at best, being maintained, although there have been major drawdowns and increased brackishness in many important aquifers. Because demand remains constrained by the shortage of desalinated water, current per capita potable water consumption is only about one-fourth that in the United States. As the result of major desalination plant construction programs in Arab countries around the Gulf, we expect per capita potable water consumption to increase throughout the decade. 25X1

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Although there are hundreds of desalination plants in the Persian Gulf area, more than 90 percent of the Gulf's desalinated water comes from just 56 plants. Each of these critical plants is extremely vulnerable to sabotage or military action. The concentration of this critical plant capacity in 29 locations heightens the risk of a successful military or terrorist attack. Within each plant, disruption of any of several critical elements could shut down the desalination process. If replacement of major capital equipment were required, these desalination plants could be inoperable for several months, with up to two years required for complete reconstruction in the absence of contingency planning. 25X1

The Iran-Iraq war drove home to Persian Gulf countries the vulnerability of many of their industrial facilities, including their national water supplies. The Iranian destruction of Iraq's Persian Gulf oil export facilities and a Kuwaiti gas/oil separation plant early in the war provided the Arab governments graphic evidence of the ease with which their own industrial facilities could be destroyed by hostile forces. Their concerns appear to be well founded in light of Iran's demonstrated capability to target and destroy selected industrial targets. We know of no Arab government efforts, however, to increase substantially security around its desalination plants nor of any efforts to develop contingency plans to cope with a successful military, commando, or terrorist attack. 25X1

The failure of the Arab governments of the Gulf region to prepare for the possible loss of desalination facilities, in our judgment, is a significant strategic oversight. Although the consequences will vary with the extent of each country's dependence on desalination and the damage inflicted during an attack, the absence of well-developed security and emergency planning increases the likelihood of a disastrous outcome. Although the loss of a single plant would likely cause only a local hardship, successful attacks on several plants in the most dependent countries could generate a national crisis that could lead to panic flights from the country and civil unrest. Continuing hostilities would compound the Arab government's difficulty in coping with these domestic problems. 25X1

We believe a partial solution to the vulnerability of Arab water supplies may lie in regional cooperation, most likely through the Gulf Cooperation Council (GCC). The shortage of potable water common to the GCC countries, their proximity, and some economies of scale in major equipment purchases are the key factors suggesting that regional planning may be the best approach. Even with comprehensive national plans and GCC cooperation, we expect the Arab countries to turn to the West—particularly the United States and Japan—for emergency supplies and restoration assistance in the event of a successful attack. In the absence of effective contingency planning and prompt assistance from the West, the political and economic costs of disruption of Persian Gulf desalination facilities will grow as the region becomes increasingly dependent on desalination to provide potable water to its populace and industry. [redacted] 25X1



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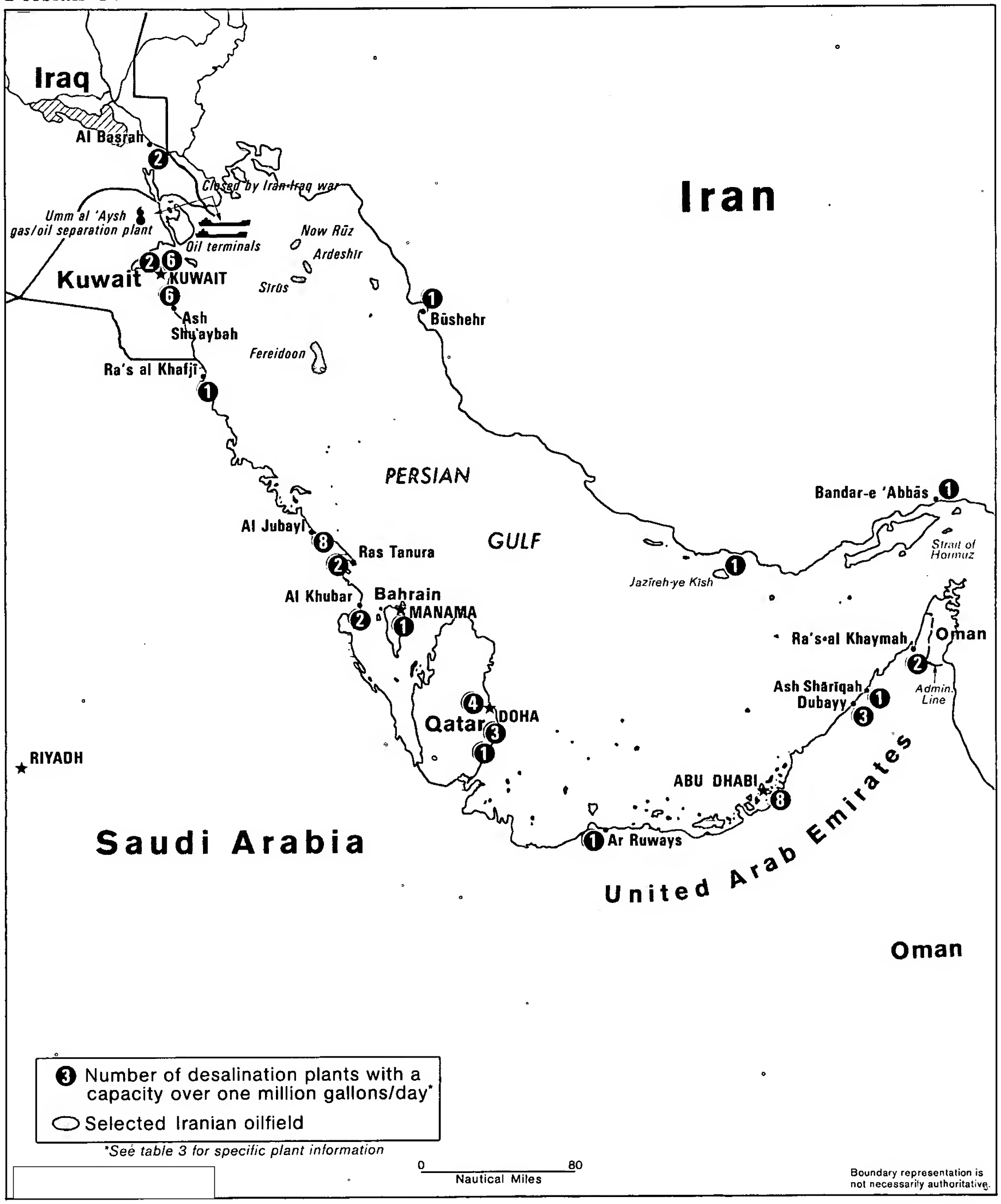
**Figure 1**
**Persian Gulf Desalination Plants**

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# Vulnerability of Persian Gulf Desalination Systems: An Emerging Security Issue [redacted] 25X1

**Introduction**
Potable water has always been a scarce commodity in the Persian Gulf region. Rainfall throughout the region is limited—typically less than 8 centimeters per year—and unreliable. Surface water sources including rivers, lakes, and dams are nonexistent in most of the countries. In the past, aquifers (water-bearing strata of permeable rocky sand or gravel) have been the major water resource in the region, although their size and quality vary widely. Before the 1950s, the region simply coped with the shortage of water, supplementing natural supplies with imported water in a few cases. Development of the petroleum industry and the resultant increase in the urban population and rise in the standard of living caused the water demand to quickly exceed available supplies. In response, the Gulf states turned to large-scale desalination of seawater as the only reliable method of obtaining adequate supplies of potable water. [redacted]

The role of desalination plants in providing potable water to the Persian Gulf countries has grown dramatically, especially over the last decade. At present, the installed capacity of desalination plants along the Persian Gulf coast is approximately 800 million gallons per day (gpd), a fivefold increase in the last 10 years, [redacted] Reliance on desalinated water for municipal and industrial water supplies has grown similarly. The most dramatic increase in the use of desalination has occurred in Saudi Arabia's Eastern Province, where production capacity has expanded from virtually nothing to more than 380 million gpd since 1972. Based on statements by Saudi water officials, we estimate that 60 to 70 percent of current potable water consumption in the province is produced in its large desalination plants.[1] [redacted]

Even Kuwait, which began its desalination program in the 1950s, has more than doubled its plant capacity in the last 10 years. Reliance on desalinated water has increased from 93 to 99 percent of potable water consumption, according to official Kuwaiti sources. The United Arab Emirates and Qatar have had similar desalination plant programs and are highly dependent on desalinated water for municipal and industrial water supplies. Although currently less dependent on desalination than the other Arab states, Bahrain, concerned about the depletion of its major aquifer, recently initiated an aggressive plant construction program that promises nearly complete dependence on desalination by the end of the decade. Only Iran and Iraq among the Persian Gulf countries have sufficient freshwater supplies to satisfy current potable water demand without large-scale desalination efforts. (See appendix A for additional details on each country's desalination program.) [redacted] 25X1 25X1

**Current Desalination Capabilities**
There are now 371 desalination plants with a capacity of 25 thousand gpd or more in operation around the Persian Gulf serving a wide variety of water consumption needs. Most of the smaller desalination plants serve only a single industrial, military, or tourist facility. Water from a few is used for agricultural purposes, but only on a limited basis. More than 90 percent of the region's installed desalination capacity is concentrated in 56 critical plants—plants capable of producing 1 million gpd or more of potable water. These critical plants are the primary, if not exclusive, source of municipal and industrial water supplies in the areas where they are located. Alternative potable water supplies are typically provided by local aquifers, which have been seriously depleted in recent years. [redacted] 25X1 25X1 25X1

[1] This paper focuses on the Persian Gulf vicinity. Areas outside the Saudis' Eastern Province are much less dependent on desalination, although per capita demand is substantially smaller. [redacted] 25X1



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**Table 1**
**Persian Gulf: Growth of Desalination Plant Capacity**

*Million gpd at yearend*

| | 1972 | 1977 | 1982 | 1983 (June) |
|---|---|---|---|---|
| **Total** | **103.9** | **177.3** | **648.6** | **799.9** |
| Bahrain | 1.0 | 7.7 | 9.8 | 9.8 |
| UAE | 7.4 | 32.6 | 157.8 | 184.2 |
| Saudi Arabia | 10.4 | 17.9 | 259.0 | 383.9 |
| Qatar | 5.0 | 26.1 | 57.0 | 57.0 |
| Kuwait | 78.3 | 78.9 | 138.7 | 138.7 |
| Iraq | 0.1 | 1.0 | 9.0 | 9.0 |
| Iran | 1.7 | 13.1 | 17.3 | 17.3 |

**Table 2**
**Persian Gulf: The Role of Critical Desalination Plants, Midyear 1983** [a]

| | Total [a] | | Critical Plants [b] | |
|---|---|---|---|---|
| | Number | Capacity *(million gpd)* | Number | Capacity *(million gpd)* |
| **Total** | **371** | **800** | **56** | **738** |
| Bahrain | 46 | 10 | 1 | 3 |
| Kuwait | 38 | 139 | 14 | 131 |
| Qatar | 21 | 57 | 8 | 53 |
| Saudi Arabia (Eastern Province) | 122 | 384 | 13 | 363 |
| UAE | 75 | 184 | 15 | 177 |
| Iraq [c] | 18 | 9 | 2 | 6 |
| Iran [c] | 51 | 17 | 3 | 5 |

[a] Includes plants whose minimum capacity is at least 25,000 gpd.
[b] "Critical desalination plants" are defined as plants capable of producing at least 1 million gpd of potable water.
[c] Includes only plants along the Persian Gulf.

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The growth of Arab dependence on desalination is the product of several forces that emerged in the 1970s. Among the most important were:

- Industrialization of the Persian Gulf coastal areas as part of major national development programs.
- Urbanization of the region caused by the massive influx of foreign workers to support industrialization and the abandonment of farming and nomadic lives by portions of the native population.
- National plans to expand municipal water services and to increase per capita water availability.

For the most part, the growth of industrialization and urbanization began to diminish in the early 1980s as petroleum revenues dropped. Nonetheless, the Arab governments have continued to expand their desalination systems—albeit at a slower rate—to meet the growing needs of municipalities.

**Potential Threats to Regional Desalination Systems**

We believe Iran presents the greatest threat to the desalination systems of the Gulf. The Iranians have already demonstrated their ability to target and destroy key industrial facilities by their strikes on Iraq's offshore oil loading terminals at Mina al Bakr and Khawr al Amaya in November 1980 and on Kuwait's gas/oil separation plant at Umm al-'Aysh in October 1981. Despite Tehran's assurances to the Arab governments that it would not attack their desalination plants, we believe that Iran has undertaken contingency planning aimed at targeting key industrial facilities in nonbelligerent Persian Gulf countries, and that the desalination plants would be among Tehran's primary targets in an expanded Persian Gulf war. 25X1

We believe terrorist attacks are also a potential threat to individual desalination facilities, although there have been no known terrorist assaults on these facilities to date. In addition to training its own commandos, Tehran reportedly has trained foreign terrorists—including radical Palestinians—in industrial sabotage methods. Libya, too, has trained and supplied terrorist groups for attacks on a variety of industrial facilities. We expect the threat posed to Arab desalination plants by these groups to increase if these organizations become more sophisticated in their operations and targeting in the years ahead. To date, however, they show little evidence of doing so. 25X1

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***The Persian Gulf Oilspill:***
***The Threat to Regional Desalination Systems***

*The current Persian Gulf oilspill is the first widespread threat to Persian Gulf desalination facilities. Oil began spilling from one well on an offshore platform in Iran's Now Ruz oilfield on 27 January as the result of damage suffered earlier in a tanker accident. Oil flows increased when two other offshore platforms in the Now Ruz field were attacked, damaged, and set afire by an Iraqi aircraft attack. Subsequently, we have confirmed* [redacted] *that Iraq attacked platforms in the Ardeshir oilfield, and they reportedly expanded their attacks to include the Sirus and Fereidoon oilfields. There is no indication, however, of additional leakages from these oilfields.* [redacted]

*There currently is no reliable reporting on the volume of oil leaking into the Persian Gulf. We estimate, however, that the wells are leaking at a combined rate of between 4,000 and 8,000 b/d. By 1 September the total oil leaked probably ranged between 1 and 2 million barrels. Reporting on the location and movement of the resulting oil slick and residue has been based on scattered, noncoordinated, and often contradictory observations. The major portion of the spill appears to be located in the central Gulf and is moving toward the Iranian shore, driven by seasonal northwesterly Shamal winds.* [redacted]

*The Persian Gulf countries have taken a number of steps—not all expected to be effective—to minimize the spill's effects. Filters and nylon netting have been placed over openings in offshore intakes, and floating booms and nets have been installed to protect surface intakes. The Saudis temporarily shut down the Al Jubayl Phase 1 plant, presumably because of problems caused by the spill. There are also reports that some systems were at least temporarily shut down in Bahrain and Qatar. These closures have not significantly affected potable water supplies to date.* [redacted] 25X1

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*The major effects of the spill on regional desalination systems are not expected until after October 1983, when the predominant winds shift to the east, moving the oil toward the Arab coast. Exposed for months to the heat and salinity of the Gulf, the lighter fractions of the crude oil have evaporated, and the remaining crude has formed tarballs and mats that stratify up to 2 meters below the surface. This seriously limits the effectiveness of current screening and filtration measures around desalination plant intakes. Although we do not expect the oil residue to cause massive damage to desalination systems, we believe that it will cause substantial plant maintenance problems and cause more closures for cleanup and repairs than has been experienced so far. Even if the leaking wells are capped soon, we expect increased maintenance problems over the next few years, possibly including distillation unit cleaning—an exhausting, expensive, and dirty process that takes several weeks. The principal effects will be substantially higher plant operating costs and occasional—and unpredictable—inconvenience from spot water shortages during plant closures for cleanup or repair.* [redacted]

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**Desalination Plant Vulnerability**

The most critical factor in the vulnerability of Persian Gulf desalination systems is the high concentration of capacity in relatively few plants at even fewer locations—92 percent of the region's productive capacity is in 56 critical plants located at 29 sites around the Gulf. In view of the region's heavy dependence on desalinated water for municipal and industrial water supplies, the entire national water systems of most smaller Arab Gulf countries as well as Saudi Arabia's Eastern Province, including Riyadh, would be in jeopardy in the event of a successful major foreign military attack. Even successful terrorist or commando attacks on individual plants could severely disrupt water availability in major cities for an extended period. [redacted] 25X1

Compounding the problem posed by the concentration of Persian Gulf desalination capacity is the easy accessibility of these critical plants. All but three of

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the Gulf's critical desalination plants use seawater feed and, accordingly, are located along the shoreline where they may be attacked by either air or naval forces. The plants are large, uniquely constructed, built near major urban and industrial centers, and—with few exceptions—are colocated with major electric power generating stations, making them both easily recognizable and high-priority military targets. The plants—built with the common objective of minimizing construction and operating costs—are compactly designed with closely built distillation units neatly aligned. [redacted]

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[redacted]

[redacted]

[redacted]

**Security Planning**
The Iran-Iraq war and the repeated threats by the Khamenei regime has made Arab governments realize that the loss of desalination facilities may have a greater impact on large segments of the populace than the loss of any other industry or commodity. Although Persian Gulf officials have expressed concern about the vulnerability of their facilities, there is little evidence that these concerns have been translated into substantive security or emergency planning measures.

Except for Kuwait, which has viewed its desalination program as strategic since its inception, there is no evidence of programs to enhance physical security, provide tighter controls on facility access, or develop a military presence in or around the facilities. [redacted] 25X6

Kuwait is the only country that has taken a positive, if only temporary, security action. In the early stages of the Iran-Iraq war, Kuwaiti desalination plants reportedly were being closely watched and protected because of the fear of attack by either country. The military reportedly was placed on alert. These security measures apparently have not remained in effect, however [redacted] making them as vulnerable to commando or terrorist attacks as plants in the other Arab states. On the other hand, the Kuwaiti plants are afforded some air defense protection by nearby surface-to-air missile batteries, which have sufficient range to provide air defense to the plants. These coastal defense units are located within a few kilometers of each plant. [redacted]

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**Contingency Planning**
Effective planning to cope with widespread destruction of desalination facilities in the Persian Gulf would be complex and expensive. Among the more important goals of such plans would be to:
- Expedite restoration of damaged desalination facilities.
- Make advance arrangements for substantial alternative supplies of potable water.
- Develop programs for the effective and equitable distribution of available water supplies. [redacted]

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Reducing the potential effectiveness of an assault on desalination facilities would depend largely on the degree of industrial security enhancement. The measures could range from maintaining routine security patrols within plant compounds to the installation of sensitive sensors or monitors around the perimeter and at critical points within the facility. Although these measures may be effective against commando or terrorist assaults, only military defense of each facility is likely to impede attacks by naval or air forces. [redacted]

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Even if restoration periods could be substantially shortened, countries with widespread damage to critical desalination plants will need to acquire substantial quantities of potable water during the interim. A number of advance-planning measures, most of them expensive, could address this situation:

- Ensure the usability of aquifer water supplies—including maintenance of existing pumps and piping—and the availability of emergency drilling, pumping, and piping equipment.

- Construct large additional water storage facilities for emergency use. These facilities should be widely dispersed inland to minimize the risk of large losses.

- Arrange to use dedicated military, industrial, and private desalination facilities for public usage, including stockpiling connectors and piping necessary to feed water into municipal systems.

- Acquire barge-mounted desalination plants that could be moved to locations where they would be most needed. Existing barge-mounted plants, such as used in Saudi Arabia and the UAE to support construction projects, could be diverted for emergency applications.

- Import potable water in empty oil tankers. This idea has been proposed by various foreign countries, particularly Japan. Although there are significant technical problems in preventing contamination of the imported water, this measure could make fairly large quantities of potable water available in a short time if Persian Gulf shipping lanes are open. 25X1 25X6

- Arrange with neighboring countries for the emergency installation of potable water pipelines. This would be least costly where the importing country is relatively close to foreign desalination plants, such as Bahrain's proximity to the major Saudi desalination complex at Al Khubar. To be effective, the piping and pumps for these lines would have to be acquired in advance. 25X1

Actual management of the distribution of available water supplies following widespread destruction of desalination facilities may prove to be the most difficult water emergency task. The cornerstone of planning for such an event would be development of an equitable and workable water-rationing program. Water allocation, distribution procedures, measures to counter fraud and black-market transactions would work best if clearly defined in advance. Major industries relying on potable water may have to be closed. In the most serious situations, established mechanisms may have to be implemented for the orderly evacuation of foreign workers. Implementation of these plans would require extensive manpower and close coordination, possibly including use of national security forces. 25X1

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**Implications**

The failure of the Arab countries of the Persian Gulf to prepare for the possible loss of desalination plants is, in our judgment, a significant strategic oversight. Although the consequences will vary with the extent of each country's dependence on desalinated water and the level of damage inflicted in an attack, the absence of security and emergency planning increases the likelihood that the worst possible outcome will occur. Moreover, as Arab reliance on desalination increases, the consequences of successful assaults on these water supplies will only become more severe. [redacted]

We do not believe that successful attacks on a single or possibly even a few desalination plants would have serious national consequences in even the most dependent countries. Given the generally localized nature of water distribution systems, the effects of a plant loss will likely be isolated. [redacted] The impact of a disruption on the area served by the plant would depend largely on the ability of the local and national government to find alternative water supplies quickly while repairing the damaged plant. [redacted]

[redacted]

Regional planning may be the best—and most likely—framework for addressing the issue of curtailed water supplies. Given its focus on economic cooperation and growing regional security role, the Gulf Cooperation Council (GCC) would be an excellent forum for this planning. All GCC members share the need for emergency water supply planning, and, in an emergency in a GCC country, the other GCC members would be in the best position to provide alternative water supplies and other support. Moreover, some economies of scale and financial burden sharing could be achieved by joint acquisition of major capital items such as stockpiled replacement equipment and barge-mounted desalination plants. A single GCC technical staff could assist member countries in developing 25X1 plant security and emergency water plans, allowing for coordination of the plans throughout the GCC [redacted] 25X1

In the event of serious damage to their desalination plants, we believe the Arab governments will turn quickly to the West—particularly the United States and Japan—for assistance at two levels: first, for emergency water supply and, second, for major desalination plant reconstruction assistance. Requests for 25X6 emergency water supply assistance may include Western 25X6 military support, such as using available naval vessel desalination units to bolster local potable water 25X6 supplies and requesting shipments of potable water or 25X6 modular desalination units. Western desalination plant manufacturers will be called upon to repair or rebuild damaged facilities. This could require as much as two years per plant to complete and involve 25X1 major Western equipment purchases and the full range of design and construction services. In the 25X6 continuing absence of improved desalination plant security and the creation of effective emergency water management plans, the vulnerability of Persian Gulf desalination plants—and the political and financial costs of disruption—will grow as the region becomes increasingly dependent on desalination to provide potable water to its growing populace and industry. [redacted] 25X1

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# Appendix A

## Persian Gulf Country Desalination Programs 25X1

**Saudi Arabia**

Rapid economic development, urbanization, and increasing per capita water consumption in the Eastern Province have surpassed the capability of Saudi Arabia's natural water resources to meet demands. As a result, since 1970 desalination capacity has steadily increased from 7 million to 500 million gpd (1983). At present, Saudi Arabia's eastern region obtains 60 to 70 percent of its drinking water from desalination plants. By 1990, more than 80 percent of the population will be connected to a water network, more than doubling the mid-1970s potable water access, when about 40 percent of the population was connected. Further strains on the system will be created by the continuing urbanization of the population and the increased water demand that has resulted from an improved standard of living. In Riyadh and Ad Dammam, for example, the population is expected to more than double by 1990, and per capita water consumption is expected to increase 60 to 70 percent.

In order to meet the growing freshwater demands, the government, under the auspices of the Saline Water Conversion Corporation (SWCC), has undertaken the largest seawater desalination plant construction and operations program in the world. The program has a capacity goal of approximately 600 million gpd by the late 1980s and double that amount early in the next century. The construction program has centered on building dual-purpose desalination and electric power generation plants, using MSF desalination plant designs. Three Eastern Province sites have been chosen for these dual-purpose plants—Al Jubayl, Al Khubar, and Ra's al Khafji (see table 3).

The Al Jubayl industrialization project is one of the largest infrastructure development programs in the world. Planned as a main industrial zone, the city will include several heavy industrial complexes and their supporting infrastructure projects. Industrialization centers around the dual-purpose power/desalination plant. The plant will be the largest in Saudi Arabia and will have a capacity of about 285 million gpd from 46 desalination units. In addition to these units, by 1984-85 the desalination plant will include a water-blending station, storage tanks, a water treatment facility, and a waste-water disposal facility. The desalination plant will service not only the industrial complex but also the city of Al Jubayl and the surrounding area, including much of the central coast of Saudi Arabia. In addition, a large portion of the produced water is to be piped to Riyadh. 25X1

The Al Khubar Phase 2 desalination plant, with a 60-million-gpd capacity, is now undergoing acceptance testing. Combined with the 1-million-gpd Phase 1 plant, it will provide the municipal supply to the main cities in the Eastern Province, including Al Khubar, Ad Dammam, Dhahran, Al Qatif, As Salwa, Rahimah, and As Sayhat. Ra's al Khafji presently provides 1 million gpd of desalinated water to industry. Phase 2, scheduled for completion in the next two years, will increase the plant's output by 5 million. Phase 3 is scheduled to add another 25 million gpd. When 25X1 complete, the three plants will provide water to much of the northeastern coastal area. 25X1

*Riyadh.* An integral part of the Al Jubayl project is supplying desalinated water to Riyadh. Riyadh previously relied on a 150-million-gpd RO desalination plant to process ground water, but rapid expansion of the city required the additional water source. In February, the King initiated water service from Al Jubayl to Riyadh through two buried, 466-km, 60-inch pipelines, the first use of desalinated seawater in Riyadh. The pipeline contains six pumping stations each, with six storage tanks holding 13.2 million gallons of water, and ultimately will supply Riyadh 25X1 with 220 million gpd. Initially, the pipeline will supply some 70 percent—about 140 million gpd—of Riyadh's potable water supplies. Distribution from storage facilities at Wasea to the municipal system—consisting of 64 tanks in four sections—will be by gravity flow. Riyadh is now modernizing its distribution system to facilitate further water distribution.

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**Kuwait**

The availability of potable water from rainfall (10 centimeters per year) and shallow wells in Kuwait is limited and unreliable. Before 1950 Kuwait coped with the situation and supplemented their needs by importing water, primarily from Iraq. The development of the petroleum industry, however, has caused rapid growth and urbanization of the population. As a result, the demand for water has increased dramatically, with current daily water consumption approximately 110 million gpd. About 105 million gpd of this water comes from desalination plants, although there are a number of wells in the populated areas.

Kuwait has experienced phenomenal growth in the past 25 years due to oil revenues. This has led to an irregular population growth with a rapid influx of workers. A rapidly rising standard of living, uncertainty about water demands, and an ambitious national development plan have meant that Kuwait has adopted a policy of installing surplus desalination capacity, and current plans are expected to meet demand up to 1990. Kuwait plans to install more than 250-million-gpd capacity by 1990, with additional capacity to be added as needed.

From the beginning of its desalination program, Kuwait adopted the dual-purpose desalination–electric power generation system using MSF distillation units as the only method of seawater desalination. The Ministry of Electricity and Water (MEW) is convinced that MSF desalination is the most reliable and economical process for large-scale plants. Kuwait's power and water supply is largely dependent on systems at three locations—Ash Shuwaykh, Ash Shuaybah, and Ad Dawhah—all operated by the Kuwaiti Ministry of Electricity and Water. Current installed capacity at Kuwait's 14 critical plants is 131 million gpd.

Kuwait has a dual distribution system—one for fresh water and another for brackish water. The brackish system, consisting of 3,400 km of pipe, is used only for irrigating public parks, gardens, and some agriculture. The freshwater network is made up of 3,000 km of pipe. Between 70 and 80 percent of Kuwait's population now has direct access to treated fresh water; the rest is served through filling stations. All citizens will have access to freshwater by 1985, when the second stage of the distribution system is to be completed.

**Qatar**

Fresh water is a scarce commodity in Qatar year round. Although small aquifers exist in many areas, they yield only limited quantities of potable water. MSF desalination has provided the bulk of Qatar's domestic and industrial water needs for some time. Of the country's 21 desalination plants, 20 plants—constituting more than 95 percent of the sheikdom's potable water supply—use seawater. These plants are about evenly divided between industrial and municipal uses, but the municipal plants are much larger. 25X1

All of the larger MSF desalination facilities are dual-purpose desalination/electric power generation plants. The plants providing municipal water supplies are concentrated in the Doha area or at Ra's Abu Fantas. 25X1

**United Arab Emirates**

Municipal demand is about 200 million gpd and is expected to grow at an average annual rate of more than 14 percent per year, according to Emirate officials. Historically, the main water source has been ground water in a gravel plain running from Al 'Ayn to Ra's al Khaymah. In the last several years, however, water has been removed at a rate significantly higher than natural replenishment, increasing the brackishness to the point that the water is unfit for human consumption, or even agricultural uses in many cases. In addition, indiscriminant well drilling and water usage has caused seawater encroachment into the aquifer. 25X1

As a result of rapidly increasing water requirements and failing natural water sources, any increase in the UAE potable water supply must be met with additional desalination facilities. Currently there are 75 operating desalination plants in the UAE providing water to municipalities, industry, tourism, and agriculture. These plants provide about 80 percent of the country's water needs. In 1981, 33 plants produced about 153.3 million gpd, more than 95 percent of all municipal water supplies in the UAE. Of these 33 plants, the 15 critical desalination plants produced 150 million gpd, or 98 percent, of the desalinated municipal supplies at that time. 25X1

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The 15 critical desalination plants include 12 MSF distillation plants, only one vapor-compression plant in Ar Ruways, and one RO plant. The 13 MSF plants are located at three sites in Abu Dhabi, two sites in Dubayy, two sites in Ra's al Khaymah, and one site in Ash Shariqah. All of the MSF plants desalinate seawater, and the water intake for each site is built on the shoreline or offshore under water. The RO plant obtains brackish water from a series of wells. With the exception of one MSF plant in Abu Dhabi and the RO plant in Ra's al Khaymah, the desalination plants are dual-purpose plants. [redacted]

With the 14-percent projected increases in water demand, the UAE will not have surplus desalination capacity in the foreseeable future. Continued construction of desalination plants, such as the 26.4 million gpd facility started in Abu Dhabi in 1983, will help satisfy the growing demand, but continuing desalination plant construction will be necessary as the country modernizes. [redacted]

**Bahrain**

Like Kuwait and the UAE, Bahrain relies almost completely on desalination for its supply of potable water. By 1981 desalination had increased to 32.3 million gpd, an increase of 57 percent over that in 1977. In contrast to those two countries, however, Bahrain desalinates predominantly brackish water. Bahrain's only large seawater desalination complex is a 3.3-million-gpd, dual-purpose MSF plant at Sitrah. Municipal water desalination plants other than the one at Sitrah produce 1 million gpd from 12 plants, all using the brackish water reversing electrodialysis (EDR) desalination process. [redacted]

Virtually all of the Bahraini population is served by piped water. Since 1977, 143 km of trunk mains and 98 km of distribution mains have been laid, and seven elevated storage tanks with a total capacity of 5 million gallons have been built. Ground storage tanks with a total capacity of 9 million gallons were completed in 1981. Industrial water supplies are also largely dependent on brackish water. [redacted]

Bahrain is pursuing a relatively ambitious desalination program because of growing demand and deteriorating freshwater supplies. Water projects are among the most significant components of the sheikdom's infrastructure development program, with capital spending during 1982-85 set at $345 million. The government believes that over the next two years—the most tenuous period—water demand will continue to rise as the quality of groundwater supplies declines. A 13-million-gpd RO plant now under construction will be operational in the mid-1980s. Bahrain is also building effluent treatment facilities to recycle water for agricultural use and thereby decrease groundwater use. The government believes the desalination 25X1
and effluent treatment program should meet the island's needs after 1985. [redacted] 25X1

**Iran and Iraq**

Iran is not dependent on desalinated water from the Gulf to service strategic industry, military needs, or to maintain an economy. In fact, in April 1983 Iran offered the other Persian Gulf countries unlimited freshwater supplies if their supplies were interrupted because of the Persian Gulf oilspill. [redacted] 25X1

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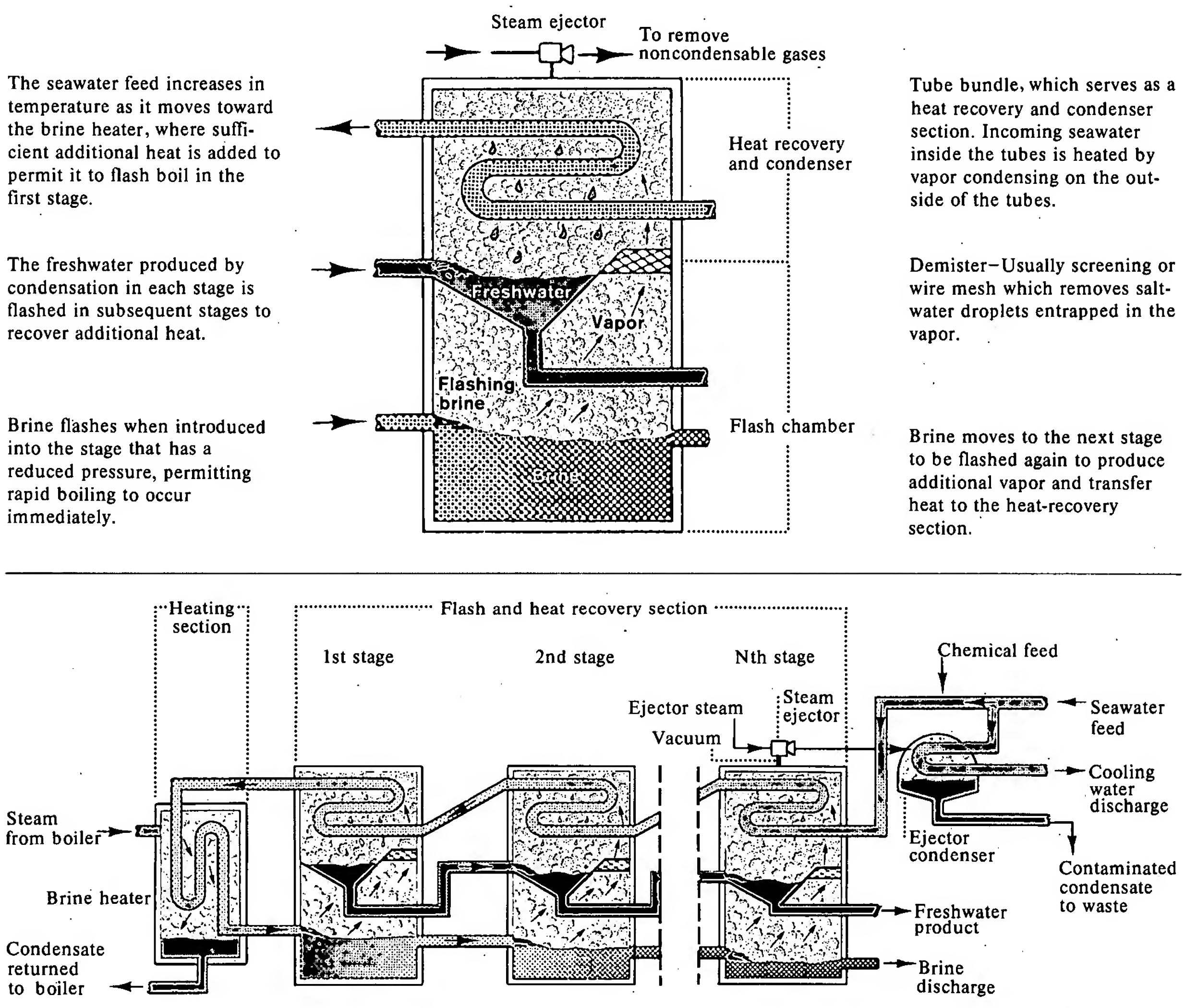
Iran has about 50 desalination plants on the Gulf used largely to support local industrial or military facilities; only nine plants provide municipal water supplies. Most of the plants use seawater MSF desalination. Iranian desalination facilities on the Gulf are concentrated at four locations: eight plants at Bandar-e 'Abbas, five at Bushehr, seven at Khark island, and three at Lavan island. Of these units, only three have capacities exceeding 1 million gpd—one each at Bandar-e 'Abbas, Bushehr, and one on Kish island, which probably provides freshwater for the island. The Bandar-e 'Abbas facility supports local industry, while the Bushehr facility and the Kish island facility serve municipal needs. [redacted] 25X1 25X1

Desalination also is not important to Iraq. The only desalination plants in the Iraq Persian Gulf region are around Al Basrah. The 19 plants there, mostly small, use predominantly brackish water to support a variety of industry in the area. There is no municipal use of desalinated water in Iraq. Only two plants have capacities exceeding 1 million gpd, one at a fertilizer plant and one at the petrochemical complex. Both use 25X1
brackish water from the Shatt al Arab waterway. [redacted] 25X1

**Figure 4**
**Multistage Flash (MSF) Process**

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## Appendix B

## Large-Scale Desalination Processes: A Technical Note 25X1

**Multistage Flash (MSF) Desalination Plants**
MSF desalination is a simple distillation process: seawater is boiled under a slight vacuum and the vapor is separated and collected. MSF plants have four discrete phases: water intake, pretreatment, brine heater, and distillation.

***Water Intake and Pretreatment.*** Seawater is pumped into the plant through an underwater pipe, aqueduct, pier arrangement, or from a seawater wetwell. With the exception of the pier, water flows to the plant by gravity. The most important equipment in the water intake is the large electric transfer pumps, usually two per unit, typically capable of handling a pumping rate two to five times the freshwater production rate.

Seawater must be pretreated before it undergoes MSF distillation to prevent corrosion or scale formation, which decreases efficiency and generally impedes liquid flow. Pretreatment consists of filtration, pH adjustment, and the introduction of various additives. The additives are disposed of with the remaining brine solution after distillation.

***Brine Heater and Distillation Unit.*** In the distillation unit, seawater enters through a tube bundle that acts both as a condenser for the distilled water and as a heat exchanger to partially heat incoming seawater (see figure 4). The incoming seawater is then heated in the brine heater. The heat source is either a dedicated heating unit or steam from the turbines of a colocated power generation plant. The steam is carried to the brine heater by pipe galleries. Following heating of the brine to the required temperature, the water is injected into the distillation unit. Each stage is maintained at a reduced pressure so that the injected water instantaneously boils, releasing significant quantities of vapor. The vapor is condensed on the outside of the tube bundle. Each stage accounts for 0.5 to 1 percent of the freshwater produced. In the first two to four stages, each stage uses a separate vacuum pump to both deaerate the water and maintain the reduced pressure. In a large MSF plant, 20 to 50 stages normally are used, and all of the remaining stages usually are connected to a single vacuum pump. Adjacent stages generally are separated by a common wall and may be built within an outer shell. 25X1

Plants operate at about 90-percent capacity utilization rate, including downtime for maintenance. Increasing this rate would be extremely difficult. Under normal operating conditions flow is conducted by the pressure difference between stages and each of the stages is isolated from the adjacent stages by the water level. An MSF desalination plant is vulnerable in that below 70 percent of design capacity the system becomes unbalanced and fails to operate. Reducing the flow by 30 percent is sufficient to lower the water level and open the stages to those adjacent, in essence making one large, inefficient stage. 25X1 25X1 25X1

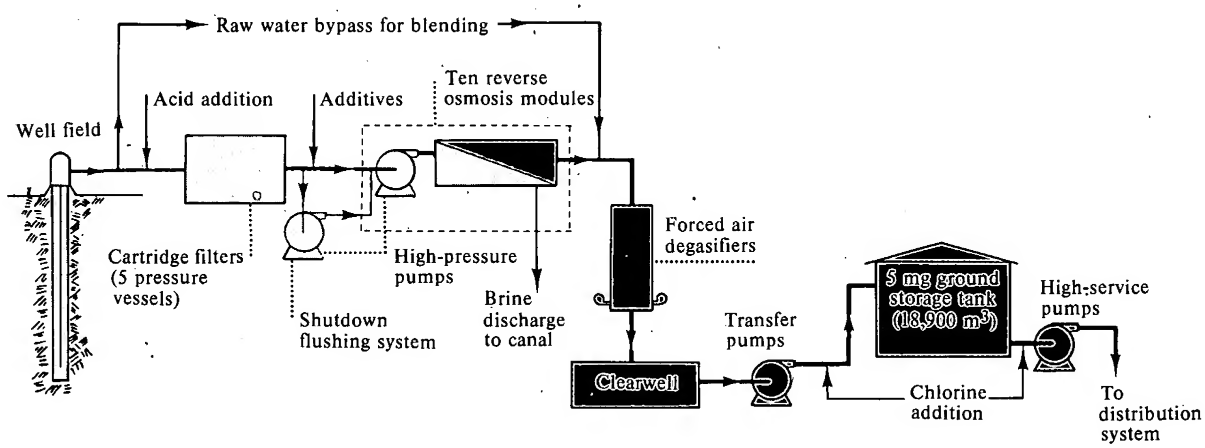
**Reverse Osmosis**
Desalination by reverse osmosis is a separation process in which the water from a pressurized saline solution is separated from the dissolved materials by flowing through a membrane. For brackish water desalination, the operating pressure generally ranges between 300 and 400 psi (20.4 to 27.2 atmospheres, or atm), and for seawater desalination it generally ranges between 800 and 1,000 psi (54.4 to 68 atm). 25X1 25X1

A reverse osmosis system consists of the following four major components (figure 5):

- ***Pretreatment.*** The incoming feedwater is treated so that it is compatible for use with and for the protection of the membranes. This usually consists of filtration, pH adjustment, and the addition of scale inhibitor.

- ***High-Pressure Pump.*** The pump energizes the pretreated feedwater to the pressure appropriate for the membrane and feedwater used.

**Figure 5**
**Five-Million-GPD Brackish Water Reverse Osmosis Facility**

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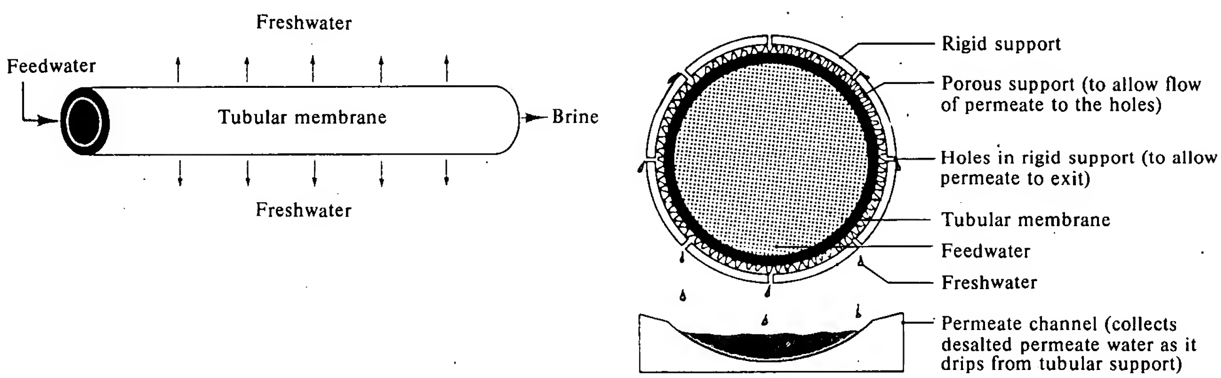
- ***Membrane Assembly.*** Saline water is pumped against the membrane in a closed container. The semipermeable membranes inhibit the passage of dissolved salts while permitting almost salt-free water to pass through. As pure water from the feed solution passes through the membrane, the remaining solution becomes more concentrated. At the same time, a valve allows a portion of the feedwater to be discharged without passing through the membrane. Under normal circumstances, the amount of potable water recovered from brackish desalination is about half of the feedwater, and for a seawater system the recovery factor is generally about 20 to 35 percent. The overwhelming majority of membranes now being used have a fixed membrane structure where the actual membrane and a porous support structure are permanantly joined together (see figure 6). Most failures in reverse osmosis plants occur because materials are deposited on the membrane surfaces or in the membrane elements.

- ***Stabilization.*** The product water from the membrane assembly usually requires pH adjustment and/or degasification and chlorine addition before being transferred to the distribution system. 25X1

The major energy requirement in an RO plant is for high-pressure pumping to the membranes. Electricity is commonly used as the primary energy source, but other sources such as diesel or steam engines with direct mechanical drives also have been used. In addition to the high-pressure pumps, other machinery such as intake pumps, chemical feeders, and instrumentation also require power. Electric power is the most convenient source for these applications. In general, overall power requirements are about 7 to 12 kWh/1,000 gal for brackish water plants, and 30 to 40 kWh/1,000 gal for seawater plants. 25X1

**Figure 6**
**Construction of a Tubular Membrane**

**Side View** | **Cross Section**

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